

# **Bedforms and Mine Burial**

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## **LONG-TERM GOAL**

The goal of this work is to develop a predictive understanding of coastal bedforms and their effect on the burial of objects on the seafloor.

## **OBJECTIVES**

The objective of the research is to develop a robust characterization of the growth of the bottom profile envelope (the range from minimum to maximum depth) in the nearshore, both in time and space, using existing data. The specific objectives are to develop

- a statistical understanding of the time evolution of the bottom profile envelope
- the likelihood of the bed elevation above envelope minimum i.e., the probability of burial
- a model for prediction of bed profile statistics and mine burial

## **APPROACH**

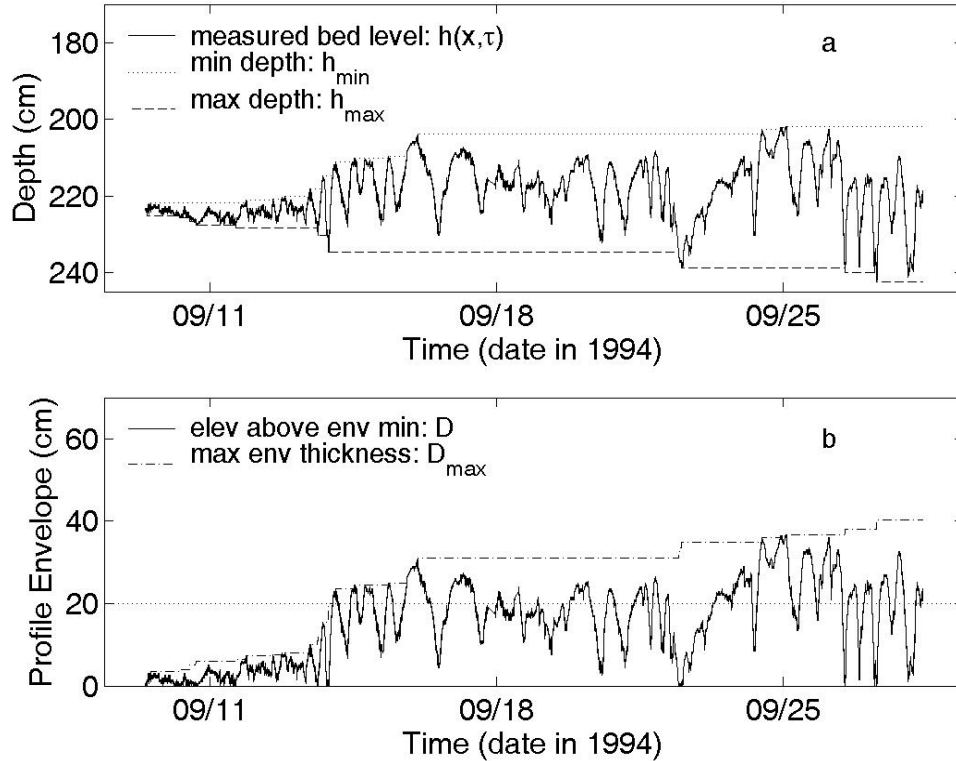
The generation and migration of bedforms (ripples, megaripples and sand bars) on sandy bottoms in the nearshore (0-8 m water depths) provides a mechanism whereby objects on the seafloor can become buried. As a bedform migrates past a mine, the mine will fall to the low point of the bedform trough before subsequently being buried by the passage of the following bedform crest. The statistics of mine burial by bedforms can be determined by the statistics of bed variability and the time evolution of the bottom profile envelope. We define the bottom profile as  $h(x, \tau)$ , and the profile envelope as spanning from  $h_{\min}(x, \tau)$  to  $h_{\max}(x, \tau)$ . The envelope has zero thickness at  $\tau=0$  (eg, when mines are placed) and as bed features form and migrate the thickness of the envelope grows with time (Fig 1).

Existing data sets (eg, Fig 1a solid line) are being used to examine the effect of bedforms on the temporal variability of the bed profile envelope (Fig 2). (See Gallagher et al. 1998a, Gallagher et al. 1998b, Gallagher et al. 2003 and [www.frf.usace.army.mil](http://www.frf.usace.army.mil) for more information on existing data sets.)

In addition, the growth, statistics, and spatial distribution of the profile envelope likely will depend on the overlying wave and current fields. Thus, the existing field data are being used to investigate relationships between the bed envelope and the measured flow parameters (Fig 3).

When  $D_{\max}$ , the maximum envelope thickness, exceeds  $W$ , the vertical scale of a mine, the mine can be buried. However, at any subsequent time, burial depends on the instantaneous elevation above envelope minimum,  $D = h - h_{\min}$ . In other words, a mine that is buried by a bedform crest can be exposed in the following trough of a migrating bedform. Thus, the likelihood of burial after a set amount of time is being examined (Fig 4).

In addition to temporal likelihood of burial, the spatial distribution of bedforms and resulting spatial likelihood of burial will also be examined. Gallagher et al. (2003) have found that, although bedforms are ubiquitous in shallow water (depth < 4 m), their spatial distribution is patchy. The spatial patterns of megaripple patches and the morphology of the bedforms (they are negatively skewed with broad flat crests and deep narrow troughs, Fig 1) become important in determining the fraction of bed area for which  $D < W$ .



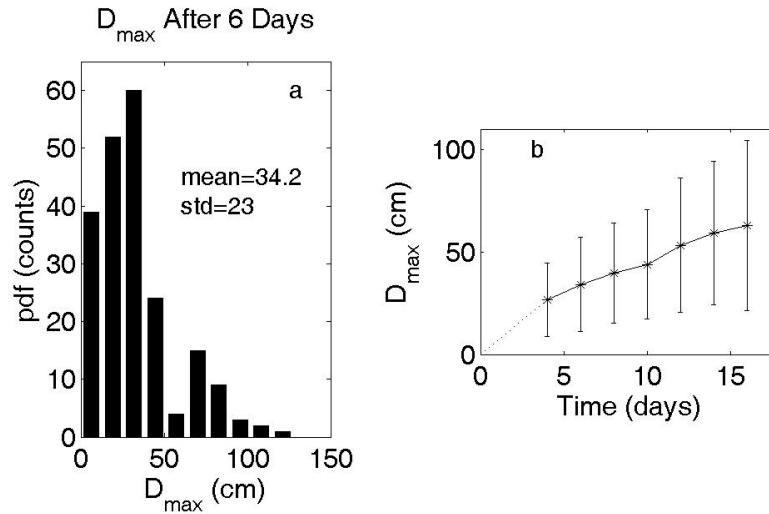
**Figure 1: a) Example time series of bed elevation [with 20-30 cm amplitude fluctuations] from a stationary sonar altimeter in about 2 m water depth (solid line). The dashed and dotted lines represent the maximum and minimum depths reached during this time period. The maximum envelope thickness,  $D_{\max}$  (dot-dashed line in b) is the difference between the dotted and dashed lines in a) [ $D_{\max}$  slowly increases with time]. The solid line in b) is the instantaneous elevation above envelope minimum,  $D$  (from the solid line in 'a' minus the dashed line in 'a'). The dotted line in b) [constant at 20 cm] represents  $W$ , the vertical scale of a mine.**

## WORK COMPLETED

The maximum bottom profile envelope thickness,  $D_{\max}$ , has been examined in water depths from 1.5 – 5 m using two months of data from eleven sonar altimeters during the Duck94 Nearshore Field Experiment.  $D_{\max}$  was calculated for 4-, 6-, 8-, 10-, 12-, 14-, and 16-day windows (with 50% overlap). A histogram of  $D_{\max}$  for the 6-day window is shown in Fig. 2a. Observed mean and standard deviation of  $D_{\max}$  for each window is shown in Fig 2b as a function of time (or window length). The observed  $D_{\max}$  has been shown to depend on normalized significant wave height,  $H_{\text{sig-norm}}$  (measured in 8 m depth and normalized by the water depth at the sensor). The slopes of the best-fit line between  $H_{\text{sig-norm}}$  and  $D_{\max}$  are calculated and shown to change as a function of window length (Fig 3).

Results from the study of bed profile envelope characterization are discussed below and a manuscript describing that work is being prepared for publication. In addition, longer time series of bed level fluctuation (bipod data, FRF CRAB data) will be used to extend the statistics of bed envelope growth to include larger scale (erosion and accretion, sand bar migration) and seasonal changes.

Work is now underway to quantify the likelihood of burial of an object (as a function of both time and space). To do this, the instantaneous elevation of the bed above envelope minimum,  $D$ , at the end of a set time window (4, 6, 8, 10, 12, 14, and 16 days) is compared to a threshold elevation  $W$  (the vertical scale of a mine, here 20 cm is used, dotted line in Fig 1b). If  $D > W$  then an object is buried and if  $D < W$  then an object is exposed. Time windows are moved in 1 hr increments, thus hourly measures of “buried/not buried after X days” are obtained. Percent burial,  $P$ , is calculated as the number of buried observations divided by the total number of observations (Fig 4). Hourly estimates give over 1000 observations from one sensor for the 2 month-long experiment (there are 11 sensors).



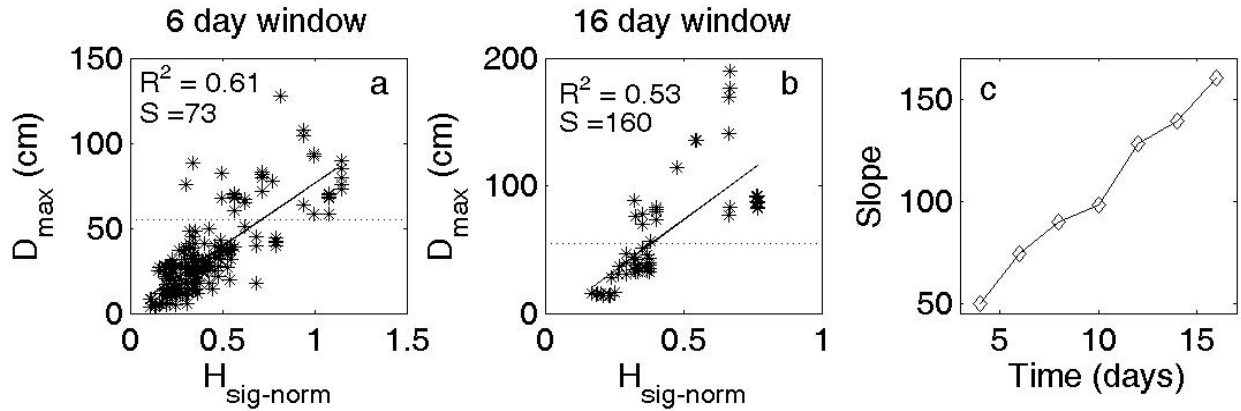
**Figure 2. a) Histogram of envelope thickness for 6-day window. Two months of data were used, with  $\tau=0$  starting every 3 days (50% overlap) giving 19 estimates for each of 11 sensors. b) Mean and standard deviation of envelope thickness are plotted versus time [increasing monotonically from about 25 cm at 4 days to 62 cm at 16 days] (with window lengths of 4, 6, 8, 10, 12, 14, and 16 days, with 50% overlap, giving 29, 19, 14, 11, 9, 7, 6 estimates for each window). The dashed line is drawn to (0,0) since at  $\tau=0$  the envelope has zero thickness by definition.**

## RESULTS

The histogram of  $D_{\max}$  after 6 days (Fig 2a) shows a peak at about 30 cm. This is in agreement with observations of megaripples, which have amplitudes of 10-50 cm. The second small peak between 60 and 80 cm corresponds to larger-scale changes in the morphology. This second peak existed, but was not as pronounced for the other data windows. The large standard deviations associated with the means (Fig 2b) are the result of using all observations for the two month period including both megaripples, which give  $D_{\max}$  below about 50 cm, and larger-scale changes, which give  $D_{\max}$  above about 50 cm. In the scatter plot of  $D_{\max}$ , plotted versus  $H_{\text{sig-norm}}$  in Figure 3a and b, a dotted line (at about 55 cm) suggests a separation between  $D_{\max}$  owing to megaripples and  $D_{\max}$  owing to larger-scale morphology changes. As expected, the larger  $D_{\max}$ 's are associated with larger waves. When wave energy increases, more sand is moved and larger morphological changes take place.

It was proposed as part of this study that  $D_{\max}$  would increase with time following an exponential taper (increase quickly at first and then taper off to a maximum or asymptotic value).  $D_{\max}$  does increase with time (Fig 2b) but the exponential trend is not observed. By increasing the time over which  $D_{\max}$  develops (by using longer time series and longer time windows), it is expected that this hypothesis will hold. The existing time series from sonar altimeters (only 2 months long) will be supplemented with other longer data sets (mentioned in the original proposal) to find the hypothesized asymptotic envelope maximum.

$D_{\max}$  has been compared with average normalized significant wave height,  $H_{\text{sig-norm}}$  (Fig 3a and b).  $D_{\max}$  and  $H_{\text{sig-norm}}$  are positively correlated, where larger  $D_{\max}$  calculated from larger morphological changes tends to be associated with larger waves. In addition, the slopes of the best fit lines between  $D_{\max}$  and  $H_{\text{sig-norm}}$  increases with time (window length) (Fig 3c). This finding indicates that the relationship between  $D_{\max}$  and  $H_{\text{sig-norm}}$  changes with time such that after 16 days a given  $H_{\text{sig-norm}}$  gives a larger  $D_{\max}$  than after 6 days.

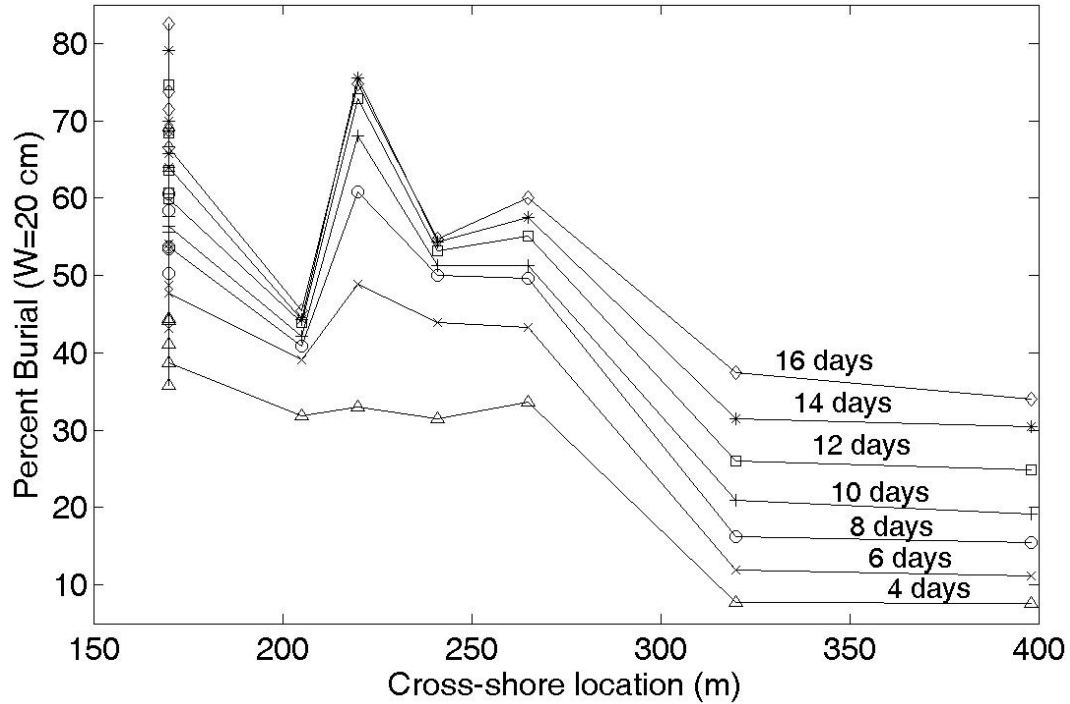


**Figure 3. Maximum envelope thickness,  $D_{\max}$ , after a) 6 and b) 16 days versus normalized significant wave height,  $H_{\text{sig-norm}}$ . [Scatter plots showing a positive correlation]. Solid lines are least squares best-fit lines to the data (asterisks).  $R$  and  $S$  are correlation coefficients and slopes of the best-fit lines. Dotted lines are to illustrate possible separation between megaripple-scale and bar-scale morphological variability. c) Slopes,  $S$ , of best-fit lines between  $D_{\max}$  and  $H_{\text{sig-norm}}$  versus time (see Table 1 for all data).**

**Table 1. Slopes and correlation coefficients of best-fit line between  $D_{max}$  and  $H_{sig-norm}$  (see Fig 3).**

window (days)	4	6	8	10	12	14	16
Slope, S	49	73	89	97	128	139	160
$R^2$	0.55	0.61	0.66	0.59	0.56	0.54	0.53

$H_{sig-norm}$  was averaged over the whole time window, thus conditions that do not contribute to the envelope growth could have a significant effect. For example, one large wave event during otherwise low wave conditions could generate erosion and therefore a large envelope, but the low waves would reduce the average wave height. This effect could make the best-fit line slopes anomalously steeper for longer time windows. Normalized maximum significant wave height,  $H_{max-norm}$ , during the time windows was also investigated to attempt to eliminate this averaging bias. Although the correlation coefficients were not as good for  $H_{max-norm}$  as they are for  $H_{sig-norm}$  (Table 1), an increase in best-fit line slopes with time was still observed. Further investigation of this effect will help elucidate a predictive relationship between waves and  $D_{max}$ . Various fluid parameters (mean, RMS, total near-bottom water velocity, etc.) calculated from current meters co-located with the altimeters were not as well correlated with  $D_{max}$  (not shown) as the offshore significant wave height.



**Figure 4. Percent burial versus cross-shore location and for each of the time windows. [P increases with time and increases in shallow water. In the surf zone,  $P=45-75\%$  after only 8 days. Outside the surf zone,  $P=16\%$  after 8 days and  $P=35\%$  after 16 days.]**

Percent burial,  $P$ , is calculated as the number of observations of burial after a set amount of time, divided by the total number of observations. Burial is observed when  $D > W$  at the end of the time window and it is estimated every hour, thus there are hourly observations of “buried/not buried after  $X$  days”.  $P$  is observed to increase with time and  $P$  is higher shallow water.

As time goes by and waves work the sediments on the seafloor, megaripples are generated and migrate, erosion and accretion take place and both  $D_{\max}$  (Fig 2b) and  $P$  increase (Fig 4). In the shallow water of the surf zone ( $x < 250$  m in Fig 4) where waves break and currents are strong, more energy is available to move sediment and these morphological processes occur more quickly. For example, for  $x=200$ -250 m there was significant erosion/accretion owing to bar migration during the experiment, thus an object on the seafloor in this region would become more deeply buried. These data resulted in a value of  $P$  that was large, ie, even with bedforms migrating past the object, the object was buried 45-75% of the time after 16 days. In addition, this condition was reached quickly, after only 8 days. In deeper water ( $x > 250$  m in Fig 4), less energy reaches the seafloor and  $D_{\max}$  (not shown) and  $P$  are smaller and their temporal development occurs more slowly (only 16% burial after 8 days and only 35% burial after 16 days). As this study progresses, the relationships between  $D_{\max}$ ,  $P$ , wave energy, water depth and time will be quantified to be used as predictive tools.

## **IMPACT/APPLICATION**

The threat of mines has an enormous impact on Naval operations. Methods exist for search and identification of proud mines, but the potential existence of buried mines is of considerable concern. This work will help to describe the process of mine burial by bottom bedform movement, and will quantify the expected time scales, probabilities and depths of burial in the nearshore.

## **TRANSITIONS**

This work has not yet lead to any transitions.

## **RELATED PROJECTS**

This work is part of the Mine Burial Program, a coordinated effort to study all processes of mine burial including impact and scour burial.

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Gallagher, E.L., Elgar, S., and Thornton, E.B. (1998b) Megaripple migration in a natural surf zone. *Nature*, 394, 165-168.

Gallagher, E.L., E.B. Thornton and T.P. Stanton (2003) Sand bed roughness in the nearshore, *J. Geophysical Research*, 108(C2), 3039.

## **PUBLICATIONS**

Gallagher, E.L., E.B. Thornton and T.P. Stanton (2003) Sand bed roughness in the nearshore, *J. Geophysical Research*, 108(C2), 3039.

Gallagher, E.L. (2003) A note on megaripples in the surf zone: evidence for their relation to steady flow dunes, *Marine Geology*, 193, 171-176.